LOAD FLOW STUDY IN POWER SYSTEM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In
Electrical Engineering
BY

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& AMIT KUMAR MALLICK (107EE016)

Department of Electrical Engineering
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CERTIFICATE

This is to certify that the thesis entitled, "LOAD FLOWS STUDY IN POWER SYSTEM" submitted by Bhabani Sankar Hota and Amit Kumar Mallick in partial fulfilments for the requirements for the award of Bachelor of Technology Degree in Electrical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date: 09.04.2011
Place: Rourkela

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Date: 09.05.2011
Place: Rourkela

LOAD FLOW STUDY IN POWER SYSTEM

Abstract

This paper presents a brief idea on load flow in power system, bus classification ,improving stability of power system ,flexible ac system, various controllers of FACTs and advantages of using TCSC in series compensation .It presents the modeling scheme of TCSC and the advantages of using it in power flow network. The plots obtained after simulation of network using matlab both with and without TCSC gives fair idea of advantages on use of reactive power compensators.

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FIGURE

CHAPTER I

INTRODUCTION TO LOAD FLOWS

1.1 INTRODUCTION

In a three phase ac power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow. Power flow studies provide asystematic mathematical approach for determination of various bus voltages, there phase angle active and reactive power flows through different branches, generators and loads under steady state condition. Power flow analysis is used to determine the steady state operating condition of a power system. Power flow analysis is widely used by power distribution professional during the planning and operation of power distribution system.

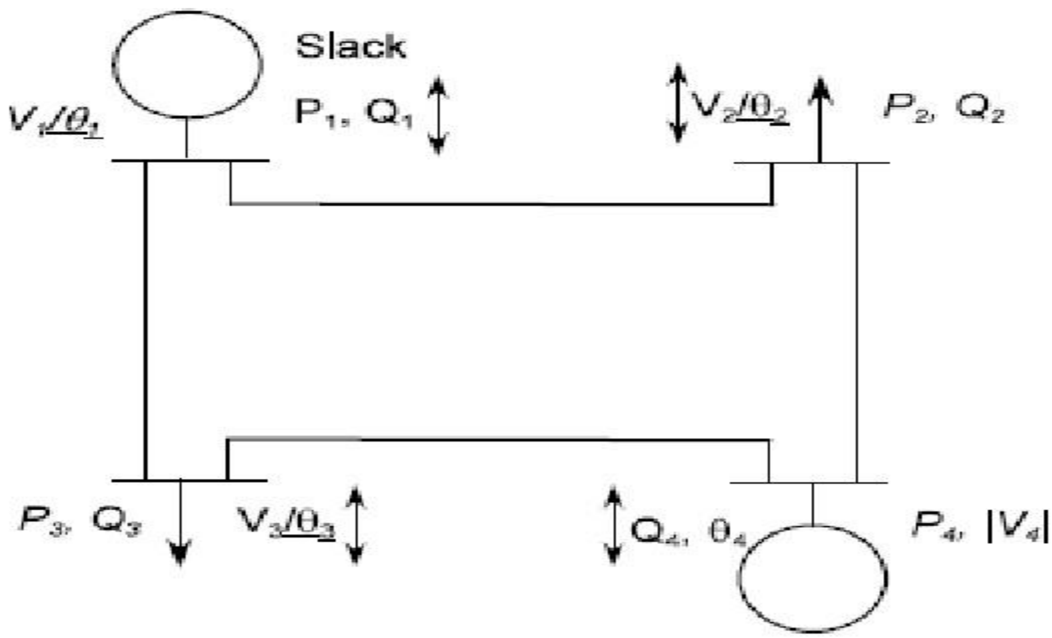


Fig 1.1

There three methods for load flow studies mainly
#Gauss siedel method
Newton raphson method
Fast decoupled method.

1.2 OBJECTIVE OF LOAD FLOW STUDY

- Power flow analysis is very important in planning stages of new networks or addition to existing ones like adding new generator sites, meeting increase load demand and locating new transmission sites.
- The load flow solution gives the nodal voltages and phase angles and hence the power injection at all the buses and power flows through interconnecting power channels.
- It is helpful in determining the best location as well as optimal capacity of proposed generating station, substation and new lines.
- It determines the voltage of the buses. The voltage level at the certain buses must be kept within the closed tolerances.
- System transmission loss minimizes.
- Economic system operation with respect to fuel cost to generate all the power needed
- The line flows can be known. The line should not be overloaded, it means, we should not operate the close to their stability or thermal limits.

1.3 BUS CLASSIFICATION

A bus is a node at which one or many lines, one or many loads and generators are connected. In a power system each node or bus is associated with 4 quantities, such as magnitude of voltage, phage angle of voltage, active or true power and reactive power in load flow problem two out of these 4 quantities are specified and remaining 2 are required to be determined through the solution of equation. Depending on the quantities that have been specified, the buses are classified into 3 categories.

VARIABLES AND BUS CLASSIFICATION

Buses are classified according to which two out of the four variables are specified

- **Load bus**: No generator is connected to the bus. At this bus the real and reactive power are specified.it is desired to find out the volatage magnitude and phase angle through load flow solutions.It is required to specify only Pd and Qd at such bus as at a load bus voltage can be allowed to vary within the permissible values.

- **Generator bus or voltage controlled bus**: Here the voltage magnitude corresponding to the generator voltage and real power Pg corresponds to its rating are specified.It is required to find out the reactive power generation Qg and phase angle of the bus voltage.

- **Slack (swing) bus**: For the Slack Bus, it is assumed that the voltage magnitude $|V|$ and voltage phase Θ are known,whereas real and reactive powers Pg and Qg are obtained through the load flow solution.

CHAPTER II

INTRODUCTION TO FACTS

2.1 FLEXIBLE AC TRANSMISSION

Flexible transmission system is akin to high voltage dc and related thyristors developed designed to overcome the limitations of the present mechanically controlled ac power transmission system.

Use of high speed power electronics controllers, gives 5 oppertunities for increased efficiency.

- Greater control of power so that it flows in the prescribed transmission routes.
- Secure loading (but not overloading) of transmission lines to levels nearer their required limits.
- Greater ability to transfer power between controlled areas, so that the generator reserve margin- typically 18 % may be reduced to 15 % or less.
- Prevention of cascading outages by limiting the effects of faults and equipment failure.
- Damping of power system oscillations,which could damage equipment and or limit usable transmission capacity.

Flexible system requires tighter transmission control and efficient management of inter-related parameters that constrains today's system including –

- Series impedance- phase angle.
- Shunt impedance- occurrence of oscillations at various frequencies below rated frequency.
-

This results in transmission line to operate near its thermal rating. Eg- a 1000kv line may have loading limit 3000-4000Mw .but the thermal limit may be 5000Mw.

2.2 FACTS SYSTEM CONTROLLER

TYPES	ATTRIBUTES
NGH- SSR Damper	Damping of oscillation,series impedance control, transient stability
SVC-static var-compensator	Voltage control,var-compensation damping of oscillation
TCSC-Thyristor controlled series capacitor	Power control,voltage control,series impedance control,damping of oscillations,transient stability
Static-condensor	Voltage control,var-compensator damping of oscillations,transient stability.
Thyristor controlled phase angle regulator	Power control,voltage control,var-compensator,damping of oscillation,transient stability.
Thyristor controlled dynamic brake	Damping of oscillation,transient stability.

- **SVC**- Uses thyristor valves to rapidly add or remove shunt connected reactors and or capacitors often in coordination with mechanically controlled reactors and/or capacitors.
- **NGH-SSR damper**- a resonance damper:- A thyristor ac-switch connected in series with a small inductor and resistor across the series capacitor.

- **Statcon(static condenser)**:- A 3 phase inverter that is driven from voltage across a dc storage capacitor and whose there output voltages are in phase with the ac system voltage.when the output voltages are higher or lower than the ac system voltage the current flow is caused to lead or lag and difference in voltage amplitudes determine how much current flows.Reactive power and its polarity can be controlled by controlling voltage.

- **Phase Angle Regulator**:-The phase shift is accomplished by adding or subtracting a variable voltage concept that is perpendicular to the phase voltage of the line

- **Unified powercontrol** :- In this concept an ac voltage vector generated by a thyristor based inverter is injected in series with phase voltage.The driving dc voltage for inverter is obtained by rectifying the ac to dc from the same transmission line. In such an arrangement the injected voltage may have any phase angle relationship to the phase voltage. It is possible to obtain a net phase and amplitude voltage change that confers control of both active and reactive power.
- **Dynamic Brake** :- A shunt connected resistive load, controlled by thyristor switches. such a load can be selectively applied in each pass, half cycle by half cycle to damp any specific power flow oscillation, so that generating unit run less risk of losing synchronism ,as a result more can be transferred over systems subjected to stability constraints.

A thyristor controlled resistor in parallel with the transmission line can be used effectively to damp power swing oscillations in the transmission system.

FACT technology ensures power flow through prescribed routes, maximization of capacity, securing loading capacity enhancement under various scenanious of uprating or upgrading the lines thermal current capacity.

One of the important function of FACT is VAR compensation .

2.3 VAR-compensation is defined as the management of reactive power to improve the performance of ac power systems;maximizing stability by increasing flow of active power.

Problems forced while reactive power compensation :-

1. Load compensation
2. Voltage support.

Load compensation objectives are to increase the value of the system power factor to balance the real power drawn from the ac supply,compensate voltage regulation and to eliminate current harmonic components produced by large and fluctuating non –linear industries loads.

Voltage support objectives:- Its generally required to reduced voltage fluctuations at a given terminal of a transmission line.

Var compensation helps to maintain a substantially flat voltage profile at all levels of power transmission improves HVDC conversion terminal performance increases transmission efficiency ,controls steady state and temporary over-voltage and can avoid disastrous blackout.

Series and shunt VAR compensation are used to modify the natural electrical characteristic of ac power system.series compensation modifies the transmission or distribution system parameters while shunt compensation changes the equivalent impedance of the load.

Earlier ,rotating synchronous condensers and fixed or mechanically switched capacitors or inductors have been used for reactive power compensation. Now a days static VAR compensators employing thyristor switched capacitors and thyristor controlled reactor to provide or absorb the required reactive power have been developed. Use of selfcommutated pwm convertors with appropriate control scheme permits the implementation of static compensators capable of generating or absorbing reactive current components with faster time response.

CHAPTER III

PRINCIPLES OF REACTIVE POWER COMPENSATION

3.1 REACTIVE POWER

Power factor is defined as the ratio of real power to apparent power. This definition is often mathematically represented as Kw/Kva ,where the numerator is the active (real) power and the denominator is the (active+reactive) or the apparent power

Power Factor = Active power/Apparent power = kW/kVA

= Active power/ (Active Power +Reactive Power)

= kW/(kW+kVAr)

The higher kVAr indicates low power factor and vice versa.

HOW TO IMPROVE POWER FACTOR

Power factor can be improved by adding consumers of reactive power in the system like Capacitors or Synchronous Motors.

It can also be improved by fully loading induction motors and transformers and also by using higher rpm machines. Usage of automatic tap changing system in transformers can also help to maintain better power factor.

PRINCIPLES OF REACTIVE POWER COMPENSATION

In a linear circuit the reactive power is defined as the ac- component of the instantaneous power with a frequency equal to 100hz in 50hz system (120 hz in 60 hz system).The reactive power generated by the ac power source is stored in a capacitor or a reactor during a quarter cycle and in the next quarter cycle is sent back to the power source. Eg reactive power oscillates between ac source and the capacitor or reactor.

3.2 SHUNT COMPENSATION: By supplying reactive power near load, tension on lines , power losses minimizes and hence improving voltage regulation.

This can be achived in three ways:

(a) With a capacitor

(b)Voltage source

(c) Current source

3.3 SERIES COMPENSATION:

Here capacitors are used to decrease the equivalent reactance of a power line at a rated frequency.

Using capacitors results improved functionality through:

(a)increased angular stability of power corridor

(b)improved voltage stability

(c)optimized power sharing between parallel circuits

3.4 Following section gives information about various VAR generators:

1. **Fixed mechanically coupled switched capacitors:**
   Leading current drawn by shunt capacitors compensate the lagging current drawn by load. Due to varying load the capacitor bank may lead to over or under compensation. For this variable VAR, compensation is achieved by using switched capacitors. This is done through C.B's and relays.
   Disadvantage : Sluggish nature, unreliable, high inrush current, frequent maintainance
2. **Synchronous Condensors:**
   It is simply a synchronous machine connected to a power system. After the unit is synchronized, he field current is adjusted either to absorb reactive power as required by the ac system . Though they have a high temporary overload capacity to their advantage,
   Nowadays they are uneconomical owing to their cost and sluggish behavior to rapid load changes.
3. **Thyristorized VAR compensators:**
   With thyristorized compensators finner control over entire VAR range could be achived with faster response. They can be grouped under two categories:

   (a)Thyristor switched capacitors*:* The basic structure consists of a shunt capacitor which is split up into approximately small steps, which are individually switched in and out using a by directional thyristor switches. Each single phase branch consist of :capacitor thyristor switches, inductor to limit the the rise of current.Tsc has following properties : stepwise control, average delay of one half of a cycle no generation of harmonics since current transients component can be attenuated.

Disadvantage : VAR compensation not continuous, each capacitor bank requires separate thyristor switches.

(b)<u>**Thyristor controlled reactor:**</u> static compensators of tcr type are characterized by the ability to perform continuous control, maximum delay of one half cycle and practically no transients.

Principal disadvantage being generation of low frequency harmonic current component and higher losses when working in inductive region (eg absorbing reactive power). However the harmonics can be eliminated using filters.

(c)<u>**Combined TCR and TCS**</u>: These are charectrized by continuous control, practically no transients, low generation of harmonics and flexibility in control and operation.

(d)<u>**Thyristor controlled series compensation**</u>: It's effective in controlling sub synchronous resonance which mainly occus because of interaction between large thermal generating units and series compensated transmission system.

4. <u>**Self commutated VAR compensators:**</u>

- Their greatest advantage is drastic reduction in size, reduction of cost (because of elimination of large no of passive elements)
- and lower relative capacity requirement of semi conductor switches. It's well suited for application where space is premium. More sophisticated self commutated VAR compensators are:

    (i) Multilevel compensators
    (ii)Multilevel compensators with carrier shifted
    (iii)Optimized multilevel compensators

5. <u>**New VAR compensator technology**</u>:

    (i)Static synchronous compensators (STATCOM)
    (ii)Static synchronous series compensators
    (iii)Dynamic voltage restorer
    (iv)Unified power flow controller
    (v)Interline power flow controller
    (vi)Superconducting magnetic energy storage
    (vii)VAR generation using coupling transformer

3.5 Advantages of TCR in FACT

1. Accuracy of compensation-Very good
2. Control flexibility-Very good
3. Reactive power capacity- Lagging or leading indirect
4. Control – Continuous

5. Response Time- Fast, 0.5 to 0.2 cycles
6. Harmonics- Very high(Large size filters are needed)
7. Losses- Good but increase in lagging mode
8. Phase balancing ability- good
9. Cost-moderate

3.6 CHARACTERISTICS OF TCR:

Tcr can be used as a better series compensator which is effective in load flow control and short circuit limitations . It's because of Tcr advantages another another concept of Advanced Series Compensation of Tcr has been developed and commercialized.Tcr consists of a fixed (mainly air core) reactor of inductance L and a bidirectional thyristor value. The current in the reactor can be from maximum(thyristor valve closed) to zero (thyristor valve open) by method of firing delay angle control.It means that the closure of thyristor value is delayed wrt the peak of applied voltage in each half cycle and thus the duration of current condution intervals is controlled.A voltage 'v' is applied and ther eactor current is given by $i_l(\alpha)$,at zero angle delay (switch fully closed)and at an arbitrary angle 'α' delay angle.

3.7 THYRISTOR CONTROLLED SERIES COMPENSATOR (TCSC)

TCSC is one of the most important and best known FACTS devices, which has been in use for many years to increase line power transfer as well as to enhance system stability. The TCSC consists of three main components: capacitor bank C, bypass inductor L and bidirectional thyristors SCR1 and SCR2. The firing angles of the thyristors are controlled to adjust the TCSC reactance in accordance with a system control algorithm, normally in response to some system parameter variations. When the thyristors are fired, the TCSC can be mathematically described as follows:

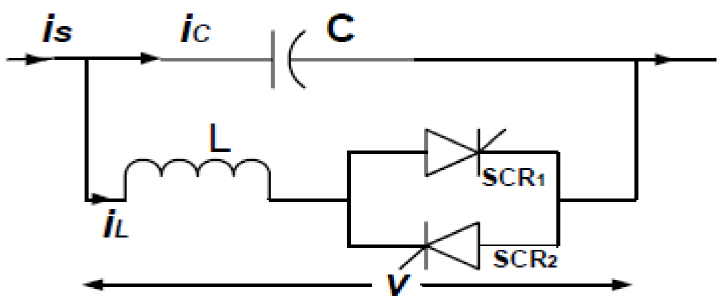


Fig3.1:**TCSC CONFURIGATION**

$$i_C = C\frac{dv}{dt}$$
$$v = L\frac{di_L}{dt}$$
$$i_S = i_C + i_L$$

where iC and i*L* are the instantaneous values of the currents in the capacitor banks and inductor, respectively; *i*S the instantaneous current of the controlled transmission line; *v* is the instantaneous voltage across the TCSC.

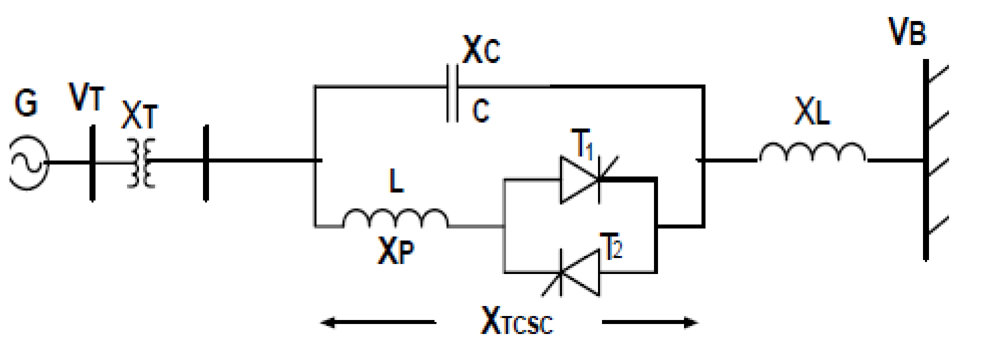


Fig3.2 : SINGLE MACHINE INFINITE BUS POWER SYSTEM WITH TCSC

<u>Thyristor Controlled Series Compensator (TCSC)</u>

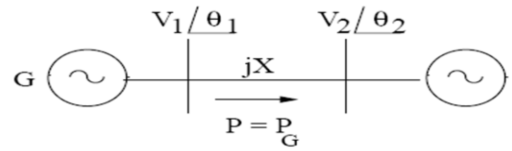
Fig 3.3: TCSC at a sub station

CHAPTER IV

AC TRANSMISSION AND STABILITY CONCEPT

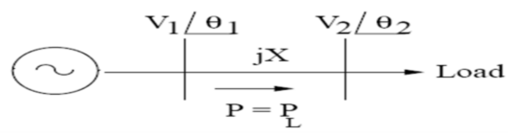
4.1 *UNDERSTANDING AC TRANSMISSION*

$$P = \frac{V_1 V_2}{X}\sin(\theta_1 - \theta_2)$$



A line transmitting power from a generating station

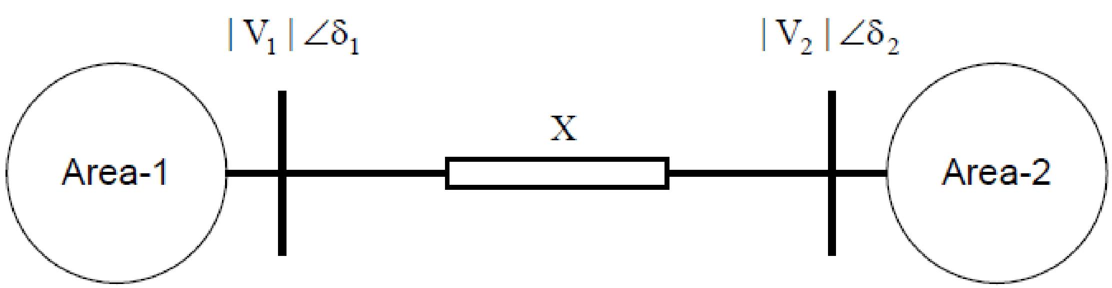
$$P = \frac{V_1 V_2}{X}\sin(\theta_1 - \theta_2)$$



A line supplying power to a load

Traditionally, AC lines have no provision for the control of power flow

Fig 4.1 Real power flow



$$P_{12} = \frac{|V1|\cdot|V2|}{X}\sin(\delta_1 - \delta_2)$$

Fig 4.2 Real power flow

Real power flow:
- $\delta 1 > \delta 2$ =>P12 is +ve: Real power flows from Area-1 to Area-2
- $\delta 1 < \delta 2$ =>P12 is -ve: Real power flows from Area-2 to Area-1

Reactive power flow:
- $|V1| > |V2|$: Reactive power flows from Area-1 to Area-2
- $|V1| < |V2|$: Reactive power flows from Area-2 to Area-1

4.2 STABILITY CONCEPT

Overview

The importance of power system stability is increasingly becoming one of the most limiting factors for system performance. By the stability of a power system, we actually mean the ability of the system to remain in operating equilibrium, or synchronism, while disturbances occur on the system. There are three types of stability, namely, steady-state, dynamic and transient stability.

Stability Definitions

In the study of electric power systems, several different types of stability descriptions are encountered. There are three types of stability namely,

(1) **Steady-state stability** –It refers to the stability of a power system subject to small and gradual changes in load, and the system remains stable with conventional excitation and governor controls.

(2) **Dynamic stability** –It refers to the stability of a power system subject to a relatively small and sudden disturbance, the system can be described by linear differential equations, and the system can be stabilized by a linear and continuous supplementary stability control.

(3) **Transient stability** –It refers to the stability of a power system subject to a sudden and severe disturbance beyond the capability of the linear and continuous supplementary stability control, and the system may lose its stability at the first swing unless a more effective countermeasure is taken, usually of the discrete type, such as dynamic resistance braking or fast valving for the electric energy surplus area, or load shedding for the electric energy deficient area. For transient stability analysis and control design, the power system must be described by nonlinear differential equations. Transient stability concerns with the matter of maintaining synchronism among all generators when the power system is suddenly subjected to severe disturbances such as faults or circuits caused by lightning strikes, the sudden removal from the transmission system of a generator and/or a line, and any severe shock to the system due to a switching operation. Because of the severity and

suddenness of the disturbance, the analysis of transient stability is focused on the first few seconds, or even the first few cycles, following the fault occurrence or switching operation. First swing analysis is another name that is applied to transient stability studies, since during the brief period following a severe disturbance the generator undergoes its first transient overshoot, or swing. If the generator can get through it without losing synchronism, it is said to be transient stable. On the other hand, if the generator loses its synchronism and can not get through the first swing, it is said to be unstable. There is a critical angle within which the fault must be cleared if the system is to remain stable. The equal-area criterion is needed and can be used to understand the power system stability. some simple figures can be utilized to graphically represent the difference between a stable case and an unstable case. In a stable case, as shown in Figure below ,if the fault is cleared at t_{c1} second, or at angle δ_{c1} where the area Aa (area associated with acceleration of the generator) equals the area Ad (area associated with deceleration of the generator). One can see that the angle reaches its maximum δ_m at t_{c1} and never gets greater than this value. In the unstable case, as shown in Figure, the fault is cleared at t_{c2} second with the area Aa greater than the area Ad. Also, it is very clear that for an unstable case, with the fault cleared at t_{c2} the angle keeps increasing and goes out-of-step, or unstable, as shown in Figure below.

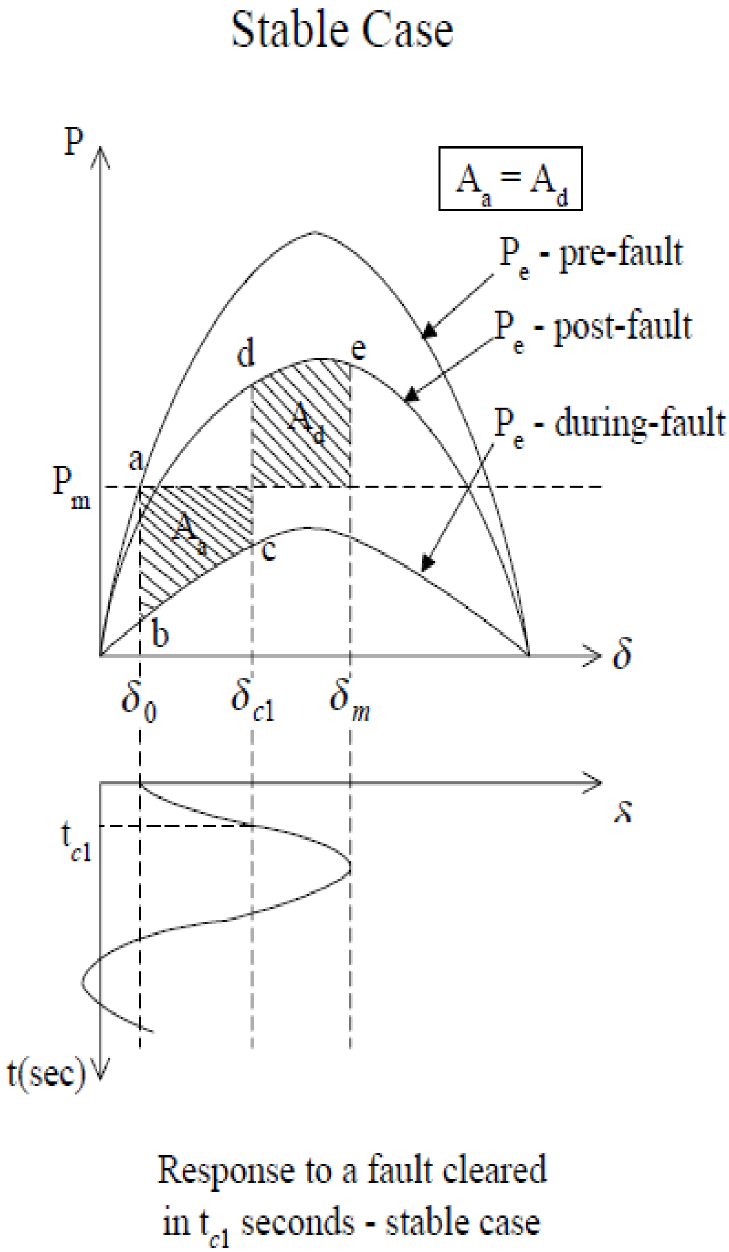


Fig 4.3: First swing analysis for a stable case

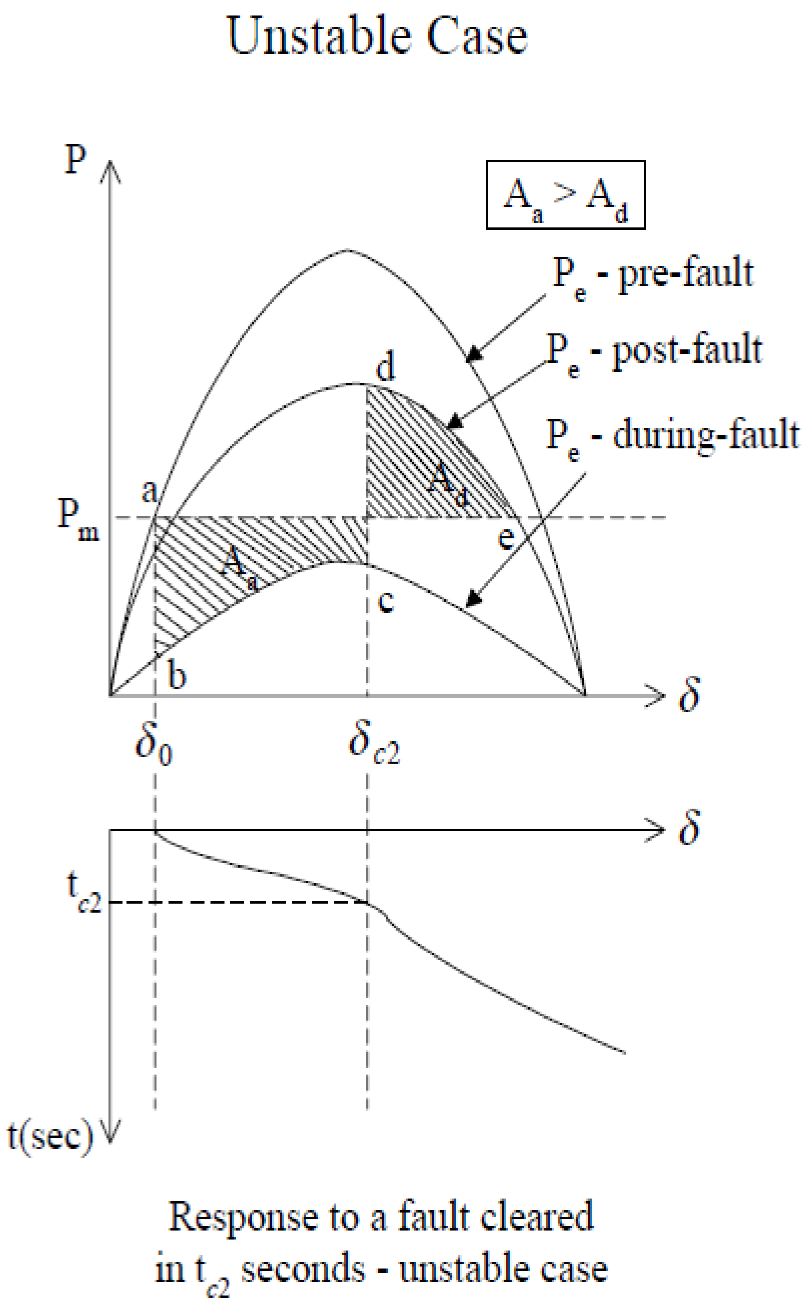


Fig 4.4: First swing analysis for a unstable case

4.3 SWING EQUATION

The moment of inertia and the accelerating torque of a synchronous machine can be related as follows

$$\frac{Jd^2\,\delta_m}{dt^2} = T_a$$

Where J=moment of inertia

δ_m= mechanical angle

And $T_a = T_M - T_e$ = accelerating torque= the difference mechanical torque and electromagnetic torque.

The relationship between the mechanical angle and the electrical angle can be expressed as

δ= = $p\delta_m/2$

Where p is the number of poles of the machine.

Then the equation of accelerating torque can be written as

$$J.2.\frac{d^2\delta}{pdt^2} = \omega_{s.}T_a = P_a$$

A commonly used constant,inertia constant H,is defined as the ratio between the stored energy in watt-seconds and VA rating of the machine ,namely

H= $\frac{1}{2}\,J\omega_{s.}/S$

It can be re-arranged as

2HS = $J\omega_{s.}$

One can relate this equation to the equation for the accelerating power P_a

$$2\frac{H}{\omega_{s.}}S.2.\frac{d^2\delta}{pdt^2} = P_a$$

If one defines

$\omega_0 = P\omega_{s.}/2$

Then the above equation can be expressed as

$$2\frac{H}{\omega_0}.\frac{d^2\delta}{dt^2} = P_a/S$$

Where allthe quantities are in their actual values.

Finally, the swing equation with the accelerating power in per unit value can be obtained as follows

$$2\frac{H}{\omega_0}.\frac{d^2\delta}{dt^2} = P_a,$$

or

$$\mathrm{M}\frac{d^2\delta}{dt^2} = P_a,$$

Where M is the angular momentum

And $\mathrm{M}=2\frac{H}{\omega_0}=\mathrm{H}/60\pi$

For the frequency of 60 hertz.

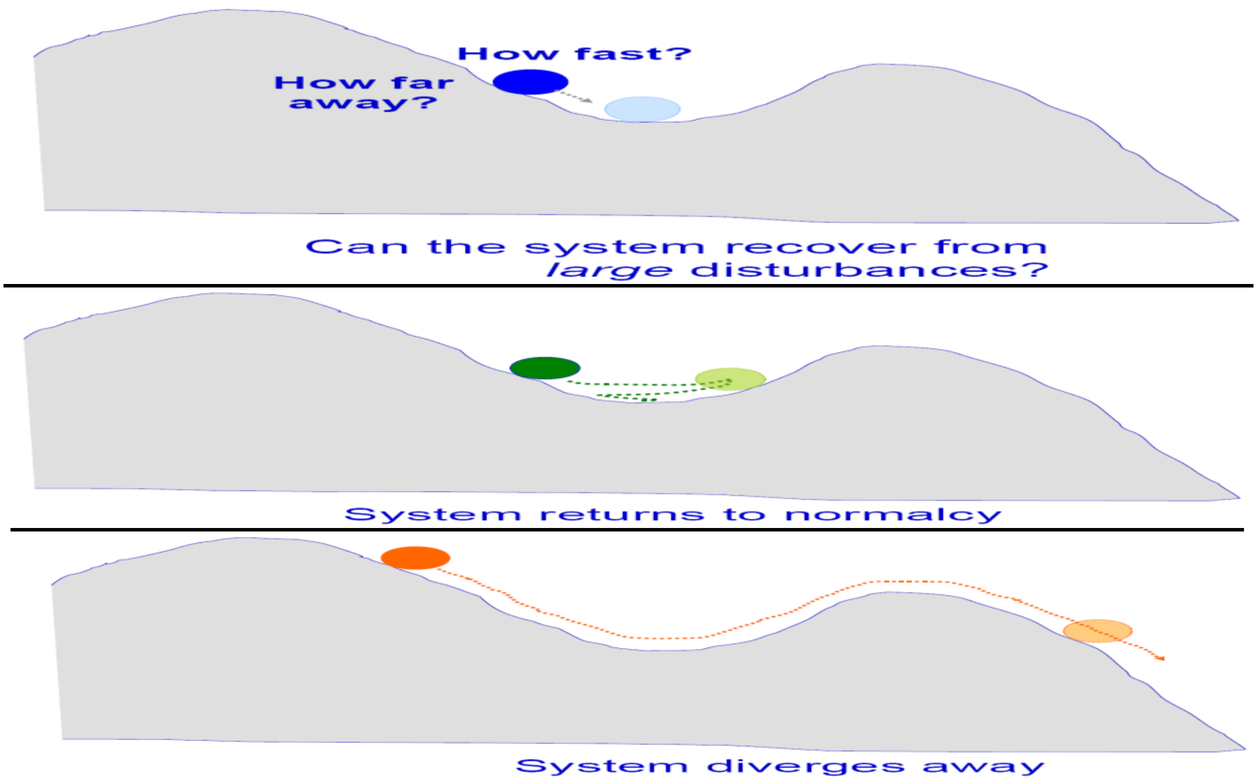


Fig 4.5:Practical example showing system stability

4.4 COMPARISION OF SOLUTION METHODS

-

- The time taken to perform one iteration of the computation is relatively smaller in case of G-S method as compared to N-R method

- The number of iterations required by G-S method for a particular system is greater as compared to N-R method and they increase with the increase in the size of the system. In case of N-R method the number of iterations is more or less independent of the size of the system and vary between 3 to 5 iterations.
- The convergence characteristics of N-R method are not affected by the selection of a slack bus whereas that of G-S method is sometimes very seriously affected and the selection of a particular bus may result in poor convergence.

CHAPTER V

NEWTON RAPHSON COMPUTER PROGRAM FOR LOAD FLOW ANALYSIS

Newton–Raphson method for power flow analysis :-

Problem statement:

The following 5 bus network was taken from G.W.Stagg & A.H.El-Abiad,computer methods in power system analysis,1968 McGraw Hill.

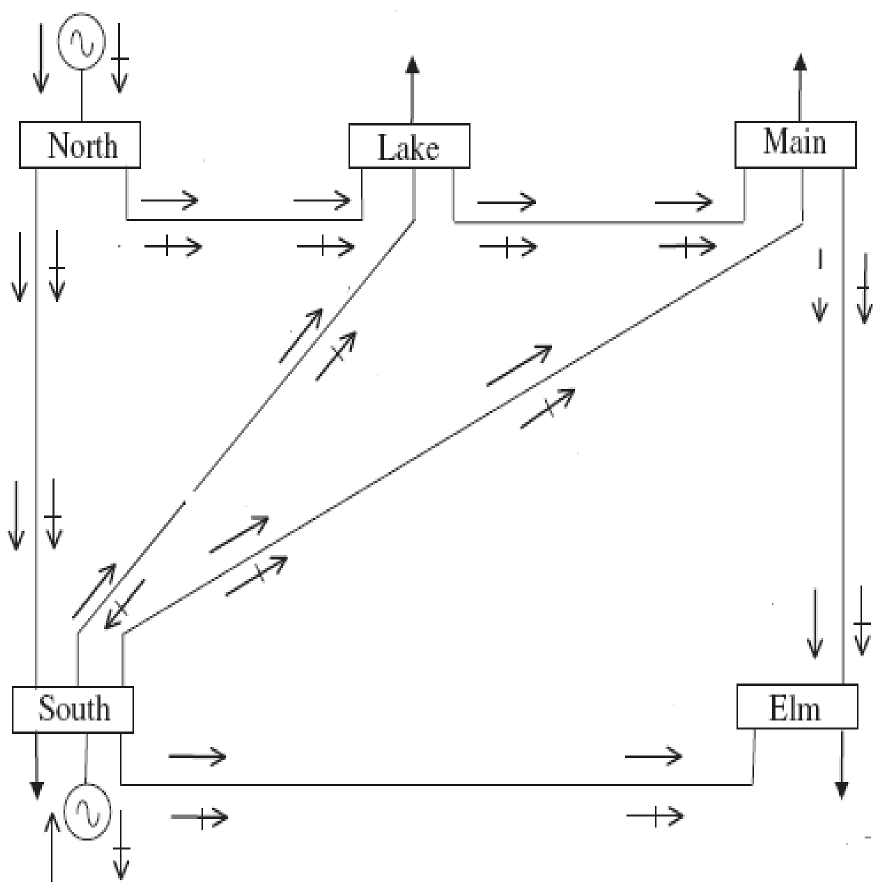


Fig 5.1: 5 bus network problem statement

- North – bus 1
- South – bus 2
- Lake – bus 3
- main – bus 4
- elm - bus 5

<u>Steps to write the matlab program and analyze the data using matlab:</u>

The sequence of steps for solution of load flow problem using N-R method are explained as follows:

Step1: Assume a suitable solution for all buses except slack bus. Assume V_P =1+j0.0 for p= 1,2….n, p≠ s, V_s= a+j0.0

Step 2: Convergence criterion is set to ∈ that means if the largest of absolute of the residues exceed ∈ the process repeated else terminated.

Step 3: iteration count is set to K=0

Step4: Bus count is set to p=1

Step 5: Say p is slack bus .if yes skip to step 10

Step 6: real and reactive powers P_p and Q_p are calculated respectively using equations

P_p=$\sum_{q=1}^{n}\{e_p\left(e_q G_{pq} + f_p B_{pq}\right) + f_p\left(f_q G_{pq} - e_q B_{pq}\right)\}$

Q_p=$\sum_{q=1}^{n}\{f_p\left(e_q G_{pq} + f_q B_{pq}\right) - e_p\left(f_q G_{pq} - e_q B_{pq}\right)\}$

Step 7: Calculate ΔP_p^k= $P_{sp} - P_p^k$.

step 8: Check for bus to be generator bus.if yes compare the reactive power Q_p^k with the upper and lower limits.

if Q_{gen} > Q_{max} set , Q_{gen} = Q_{max}

else if Q_{gen} < Q_{min} set, Q_{gen} = Q_{min}

else if the value is within the limit ,the value is retained. If the limits are not violated ,voltage residue is evaluated as $|\Delta Vp|^2$=$|Vp|^2{}_{spec}$ - $\left|V_p^k\right|^2$

and then goto step 10.

Step 9: ΔQ_p^k= $Q_{sp} - Q_p^k$ is evaluated

Step 10: bus count is incremented by 1,i.e p=p+1 and check if all buses have been accounted else,go to step 5.

Step 11: Determine the largest of the absolute value of residue.

Step 12: If the largest of the absolute value of the residue is less than $\in$ then go to step 17

Step 13: jacobian matrix elements are evaluated.

Step 14: voltage increments Δe_p^k and Δf_p^k are calculated

Step 15: calculate new bus voltages $e_p^{k+1} = e_p^k + \Delta e_p^k$ and $\Delta f_p^k = f_p^k + \Delta f_p^k$. Evaluate cos δ and sin δ for all voltages.

Step 16: Advance iteration count is K =K+1,then go to step 4

Step 17: Finally bus and line powers are evaluated and results printed.

END

<u>For the given problem statement of 5 bus network the data are as follows:</u>

DATA ENTRY

nbb = 5 ;

bustype(1) = 1 ; VM(1) = 1.06 ; VA(1) =0 ;

bustype(2) = 2 ; VM(2) = 1 ; VA(2) =0 ;

bustype(3) = 3 ; VM(3) = 1 ; VA(3) =0 ;

bustype(4) = 3 ; VM(4) = 1 ; VA(4) =0 ;

bustype(5) = 3 ; VM(5) = 1 ; VA(5) =0 ;

Generator data

ngn = number of generators

genbus = generator bus number

PGEN = scheduled active power contributed by the generator

QGEN = scheduled reactive power contributed by the generator

QMAX = generator reactive power upper limit

QMIN = generator reactive power lower limit

ngn = 2 ;

genbus(1) = 1 ; PGEN(1) = 0 ; QGEN(1) = 0 ; QMAX(1) = 5 ; QMIN(1) = -5 ;

genbus(2) = 2 ; PGEN(2) = 0.4 ; QGEN(2) = 0 ; QMAX(2) = 3 ; QMIN(2) = -3 ;

Transmission line data

ntl = number of transmission lines

tlsend = sending end of transmission line

tlrec = receiving end of transmission line

tlresis = series resistance of transmission line

tlreac = series reactance of transmission line

tlcond = shunt conductance of transmission line

tlsuscep = shunt susceptance of transmission line

ntl = 7 ;

tlsend(1) = 1 ; tlrec(1) = 2 ; tlresis(1) = 0.02 ; tlreac(1) = 0.06 ;

tlcond(1) = 0 ; tlsuscep(1) = 0.06 ;

tlsend(2) = 1 ; tlrec(2) = 3 ; tlresis(2) = 0.08 ; tlreac(2) = 0.24 ;

tlcond(2) = 0 ; tlsuscep(2) = 0.05 ;

tlsend(3) = 2 ; tlrec(3) = 3 ; tlresis(3) = 0.06 ; tlreac(3) = 0.18 ;

tlcond(3) = 0 ; tlsuscep(3) = 0.04 ;

tlsend(4) = 2 ; tlrec(4) = 4 ; tlresis(4) = 0.06 ; tlreac(4) = 0.18 ;

tlcond(4) = 0 ; tlsuscep(4) = 0.04 ;

tlsend(5) = 2 ; tlrec(5) = 5 ; tlresis(5) = 0.04 ; tlreac(5) = 0.12 ;

tlcond(5) = 0 ; tlsuscep(5) = 0.03 ;

tlsend(6) = 3 ; tlrec(6) = 4 ; tlresis(6) = 0.01 ; tlreac(6) = 0.03 ;

tlcond(6) = 0 ; tlsuscep(6) = 0.02 ;

tlsend(7) = 4 ; tlrec(7) = 5 ; tlresis(7) = 0.08 ; tlreac(7) = 0.24 ;

tlcond(7) = 0 ; tlsuscep(7) = 0.05 ;

Shunt data

nsh = number of shunt elements

shbus = shunt element bus number

shresis = resistance of shunt element

shreac = reactance of shunt element:

+ve for inductive reactance and –ve for capacitive reactance

nsh = 0 ;

shbus(1) = 0 ; shresis(1) = 0 ; shreac(1) = 0 ;

Load data

nld = number of load elements

loadbus = load element bus number

PLOAD = scheduled active power consumed at the bus

QLOAD = scheduled reactive power consumed at the bus

nld = 4 ;

loadbus(1) = 2 ; PLOAD(1) = 0.2 ; QLOAD(1) = 0.1 ;

loadbus(2) = 3 ; PLOAD(2) = 0.45 ; QLOAD(2) = 0.15 ;

loadbus(3) = 4 ; PLOAD(3) = 0.4 ; QLOAD(3) = 0.05 ;

loadbus(4) = 5 ; PLOAD(4) = 0.6 ; QLOAD(4) = 0.1 ;

General parameters

itmax = maximum number of iterations permitted before the iterative process is terminated – protection against infinite iterative loops

tol = criterion tolerance to be met before the iterative solution is successfully brought to an end

itmax = 100;

tol = 1e-12;

nmax = 2*nbb;

Proceeding as per the algorithm and developing the matlab code the results obtained are as follows:

solution

```
it =

  6

VM =

   1.0600    1.0000    0.9872    0.9841    0.9717

VA =

   0   -2.0612   -4.6367   -4.9570   -5.7649
```

PQsend =

Columns 1 through 4

0.8933 + 0.7400i   0.4179 + 0.1682i   0.2447 - 0.0252i   0.2771 - 0.0172i

Columns 5 through 7

0.5466 + 0.0556i   0.1939 + 0.0286i   0.0660 + 0.0052i

PQrec =

Columns 1 through 4

-0.8685 - 0.7291i -0.4027 - 0.1751i -0.2411 - 0.0035i -0.2725 - 0.0083i

Columns 5 through 7

-0.5344 - 0.0483i -0.1935 - 0.0469i -0.0656 - 0.0517i

Answers found out match the given results.

PROGRAM & SIMULATIONS OF NORMAL FLOW USING HADDI SADDAT SOFTWARE:

PROGRAM:

```
basemva=100; accuracy=0.0001; maxiter=10;

     %  bus      bus    volt  angle ---load--- ---generator--- injected---
     %  no       code   mag   deg   mw    mvar   mw     mvar  Qmin Qmax mvar
Busd  [1          1     1.06   0     0      0      0       0     0     0     0
       2          2     1.0    0     0      0      90.82   0     0     200   0
       3          0     1.0    0     45     14.95  0       0     0     0     0
       4          0     1.0    0     40     4.98   0       0     0     0     0
       5          0     1.0    0     60     10     10      0     0     0     0 ];
```

```
%line data
      %   bus      bus    R        X        0.5B     line code
      %   nl        nr    pu       pu        pu      tap setting
linedata = [  1     2    0.020    0.060    0.030       1.0
              1     3    0.080    0.240    0.025       1.0
              2     3    0.060    0.180    0.020       1.0
              2     4    0.060    0.180    0.020       1.0
              2     5    0.040    0.120    0.015       1.0
              3     4    0.010    0.030    0.010       1.0
              4     5    0.080    0.240    0.025       1.0 ];

Lfybus       %form bus admittance matrix for power flow
Lfnewton     %power flow solution method for power flow
Busout       % prints power flow solution
% generator data
%       generator  Ra   Xd'    H
gendata=[ 1         0    0.20   20
          2         0    0.16   4  ];

Trstab       %performs the stability analysis
```

- **RESULTS BASED ON FAULT AT BUS 1 AND LINE TO BE REMOVED TO CLEAR FAULT IS 12, FAULT CLEARING TIME IS 0.4 SECONDS.**

SIMULATION TIME IS TAKEN 10 SECONDS TO SHOW THE DAMPING EFFECTS.

Power Flow Solution by Newton-Raphson Method

Maximum Power Mismatch = 2.82253e-010

No. of Iterations = 10

Bus	Voltage	Angle	------Load------		---Generation---		Injected
No.	Mag.	Degree	MW	Mvar	MW	Mvar	Mvar
1	1.060	0.000	0.000	0.000	46.771	11.104	0.000
2	1.050	-0.490	0.000	0.000	90.820	-4.749	0.000
3	1.027	-3.178	45.000	14.950	0.000	0.000	0.000

4	1.027	-3.362	40.000	4.980	0.000	0.000	0.000
5	1.024	-3.499	60.000	10.000	10.000	0.000	0.000
Total			145.000	29.930	147.591	6.355	0.000

Enter faulted bus No. -> 1

Enter the bus to bus Nos. of line to be removed -> [1,2]

Enter clearing time of fault in sec. tc = 0.4

Enter final simulation time in sec. tf = 10

Plot obtained:

Fig 5.2: Fault at bus 1, line removed 12

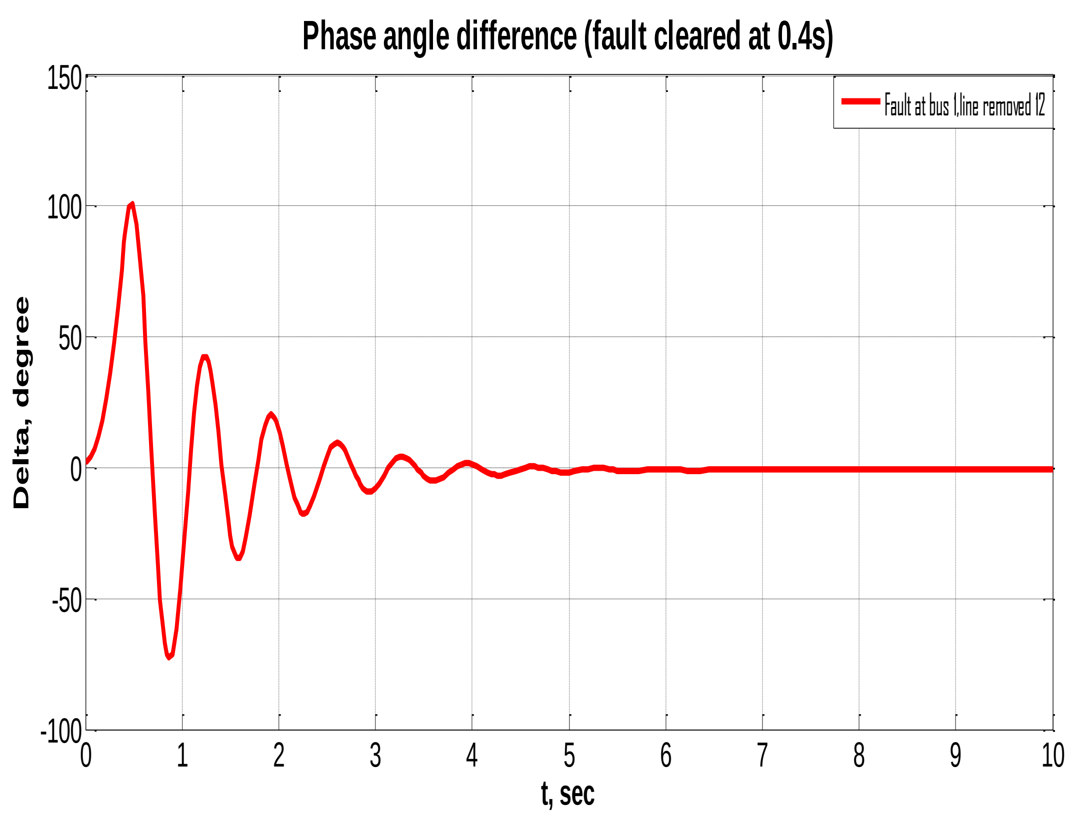


Fig 5.3: Fault at bus 2 line removed 23

:

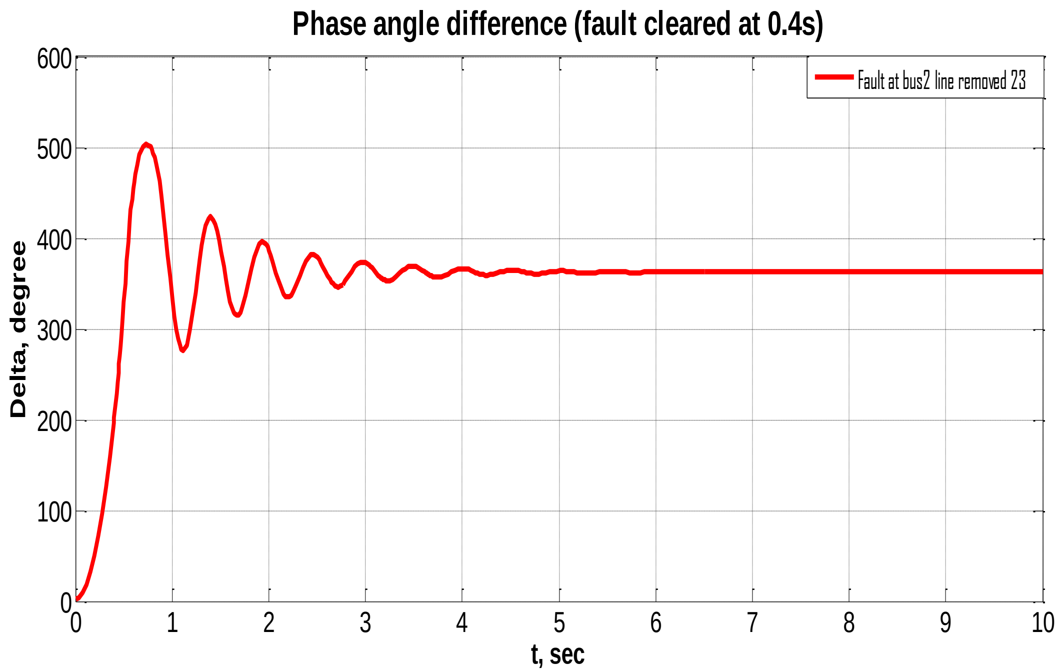


Fig 5.4:Fault at bus 2 line removed 25:

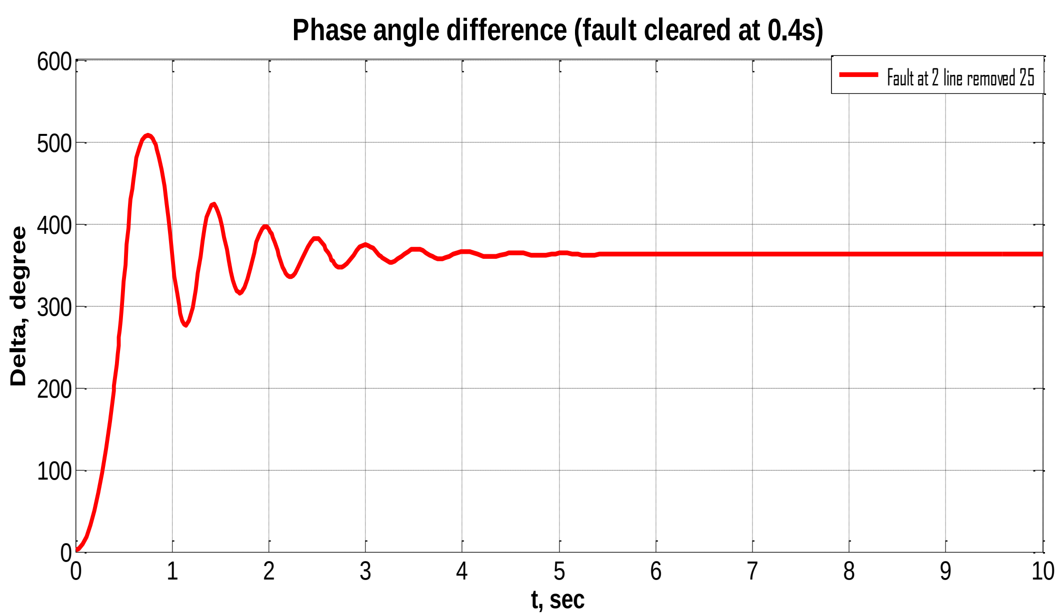


Fig 5.5:Fault at bus 3 line removed 13:

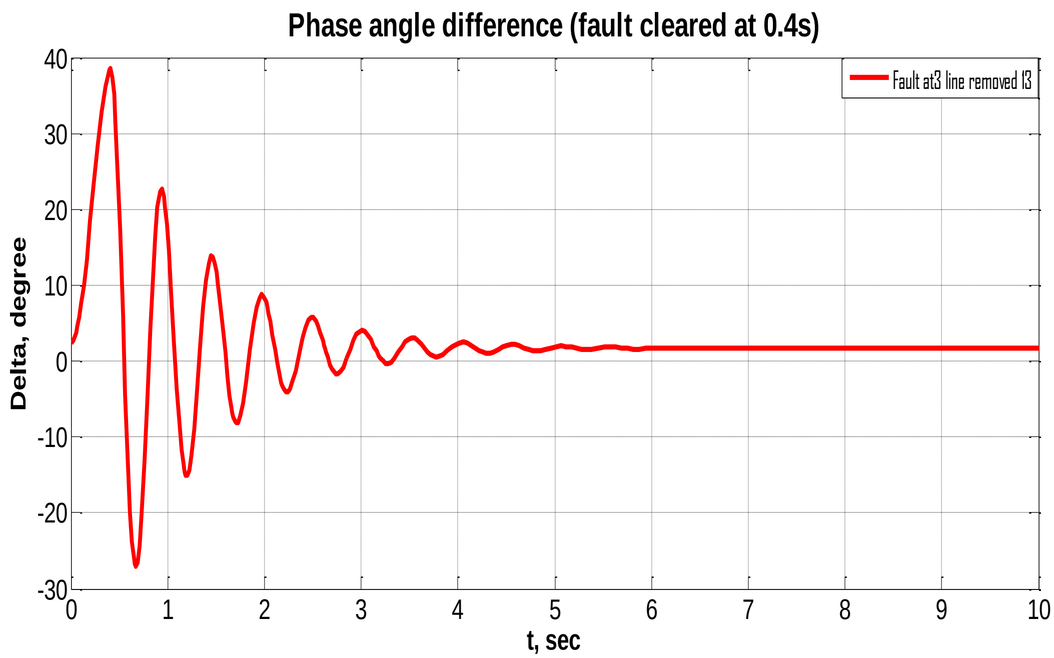


Fig 5.6:Fault at bus 3 line removed 34:

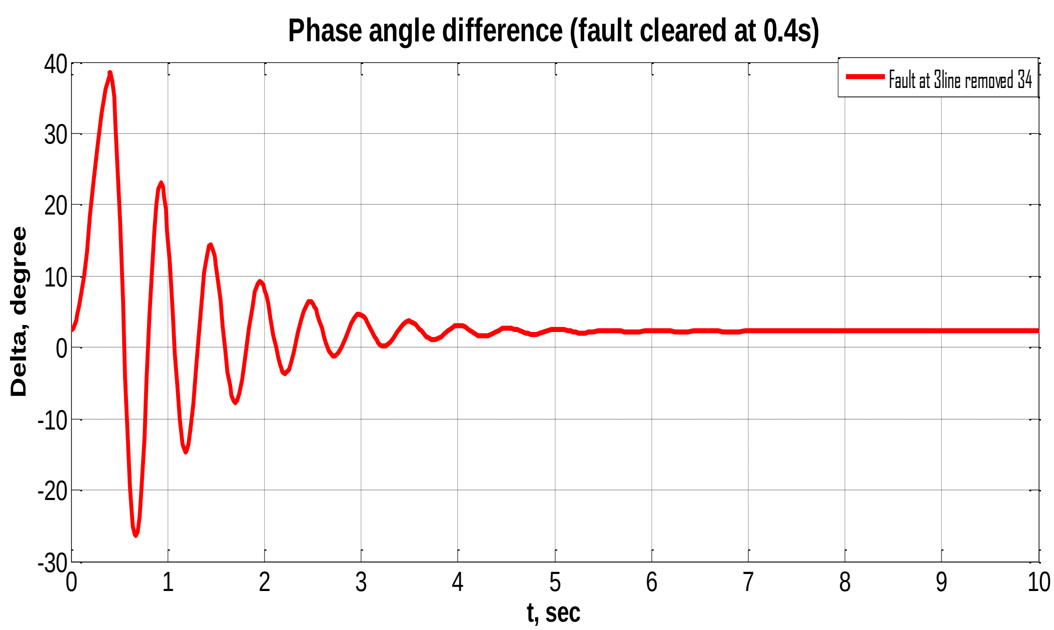


Fig 5.7:Fault at bus 4 line removed 45:

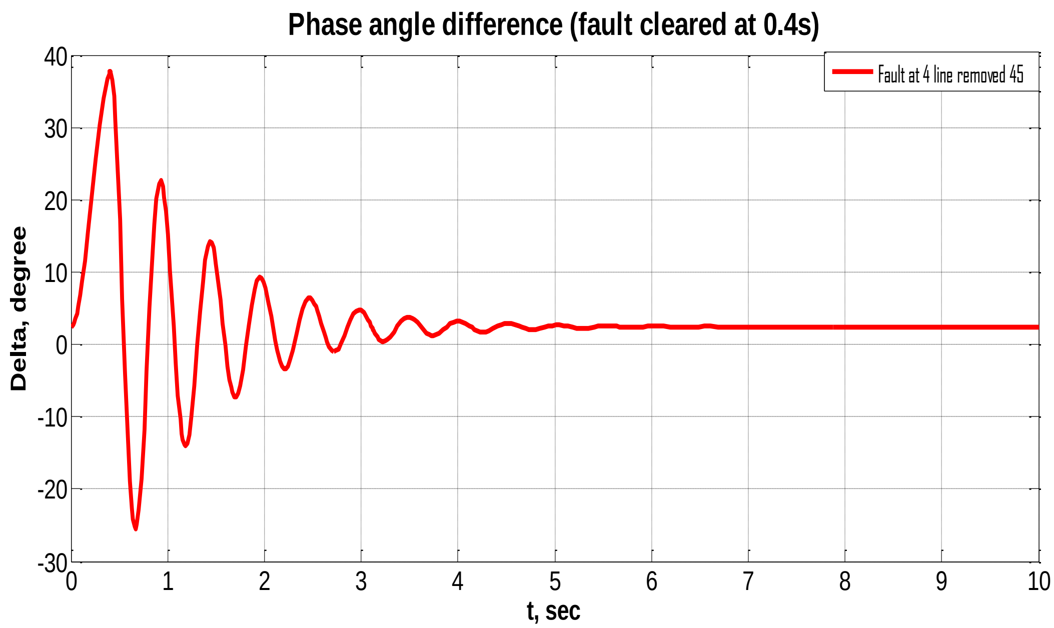


Fig 5.8: Fault at bus 4 line removed 24:

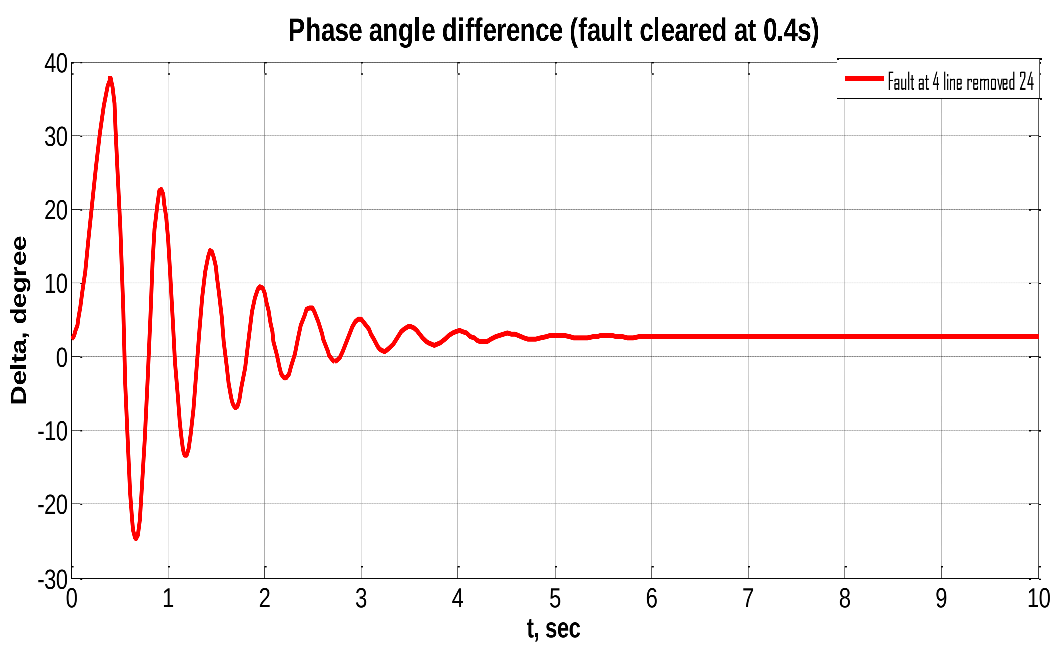
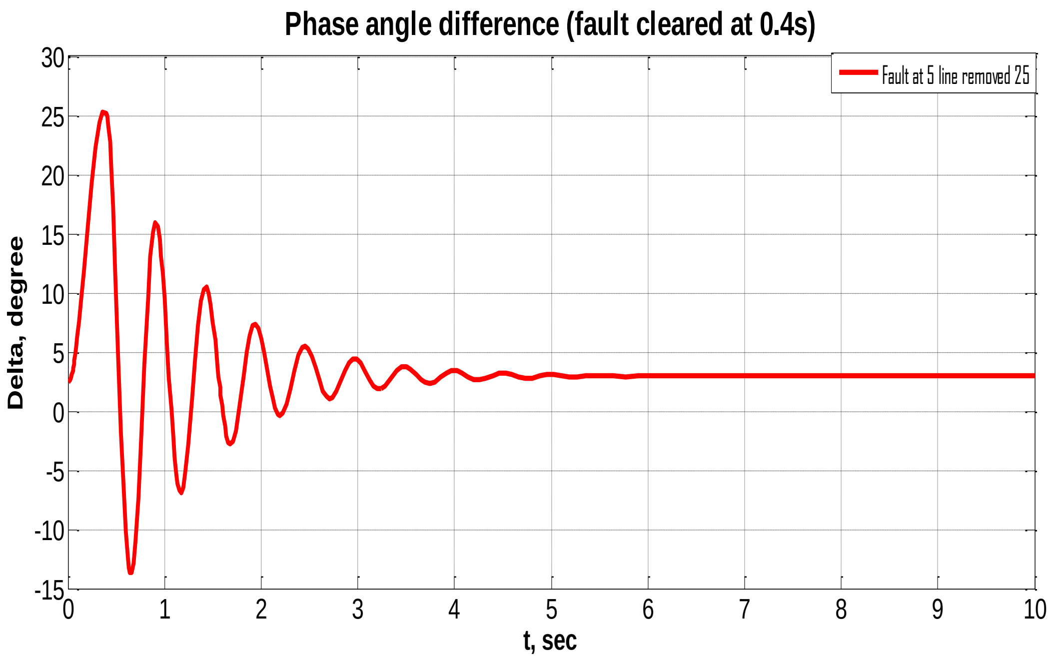


Fig 5.9:Fault at bus 5 line removed 25:



CHAPTER VI

THYRISTOR CONTROLLED SERIES CAPACITOR MODELLING SCHEME

THYRISTOR CONTROLLED SERIES CAPACITOR MODELLING SCHEME

Why we use TCSC?

There are basically two reasons for wchich we opted to use tcsc for power flow studies,they are-

1.Electromechanical damping : It provides electromechanical damping between large interconnected electrical systems by changing the reactance of any specific power line that connects them.

2.Avoiding SSR : TCSC changes its apparent impedence (as the line current confronts) for subsynchronous frequencies such that any subsynchronous resonance is avoided.

TCSC module consists of a fixed series capacitor (FC) in parallel with a thyristor controlled reactor (TCR). The TCR is formed by a reactor in series with a bi-directional thyristor valve that is fired with a phase angle α ranging between 90º and 180º with respect to the capacitor voltage.
In a TCSC, two main operational blocks can be clearly identified:-

1) External control
2) Internal control

External control directly relies on measured systems variables to define the reference for the internal control, which is usually the value of the controller reactance.

Internal control provide appropriate gate drive signals for the thyristor valve to produce the desired compensating reactance.
Hence, the external control is the one that defines the functional operation of the controller The external control may be comprised of different control loops depending on the control objectives. Additional functions for stability improvement, such as damping controls, may be included in the external control. In the diagram given below *Xm* is the stability control modulation reactance value, as determined by the stability or dynamic control loop, and *Xeo* denotes the TCSC steady state reactance. The sum of these two values yields *X'm*, which is the final value of the reactance ordered by the external control block. This signal is put through a first-order lag to represent the natural response of the device and the delay introduced by the internal control, which yields the equivalent capacitive reactance *Xe* of the TCSC. In this model, it is possible to directly represent some of the actual TCSC internal

control blocks associated with the firing angle control, as opposed to just modeling them with a first order lag function. Nevertheless, since the relationship between angle α and the equivalent fundamental frequency impedance *Xe* is a unique-valued function ,the TCSC is modeled here as a variable capacitive reactance within the operating region defined by the limits imposed by the firing angle α. Thus, $X_{emin} \le X_e \le X_{emax}$, with $X_{emax} = X_e(\alpha_{min})$ and $X_{emin} = X_e(180 \text{ deg}) = X_C$, where X_C is the reactance of the TCSC capacitor. The controller is assumed to operate only in the capacitive region, i.e. $\alpha_{min} > \alpha_r$, where α_r corresponds to the resonant point, as the inductive region associated with 90o < $\alpha < \alpha_r$ induces high harmonics that cannot be properly modeled in stability studies.

.

Equations used in the power flow implementation using TCSC

$$\dot{\delta}_1 = \omega_0 \Delta\omega_1$$

$$\dot{\delta}_2 = \omega_0 \Delta\omega_2$$

$$\dot{\omega}_1 = p_{m1} - p_{e1}$$

$$\dot{\omega}_2 = p_{m2} - p_{e2}$$

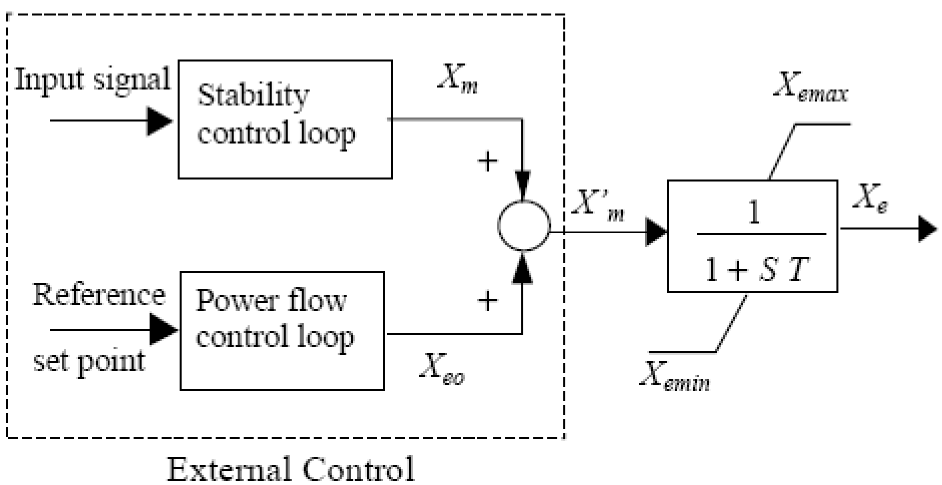


Fig 6.1: TCSC model for stability studies

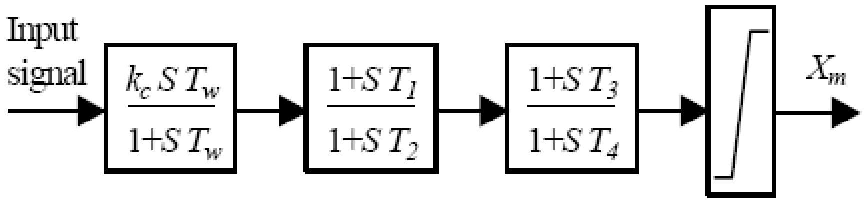


Fig 6.2 :The transfer function of stability control loop (proposed)

Transfer function obtained:

u= $K_T(\frac{sT_W}{1+sT_W})(\frac{1+sT_1}{1+sT_2})(\frac{1+sT_3}{1+sT_4})$y

where, u and y are the TCSC controller output and input signals, respectively. In this structure, Tw is usually prespecified and is taken as 10 s. Also, two similar lag-lead compensators are assumed so that T1=T3 and T2=T4. The controller gain K_T and time constants T1 and T2 are to be determined.

Power flow solution when a TCSC is implemented in the same circuit :

Network diagram:

The following 5 bus network was taken from G.W.Stagg & A.H.El-Abiad,computer methods in power system analysis,1968 McGraw Hill.

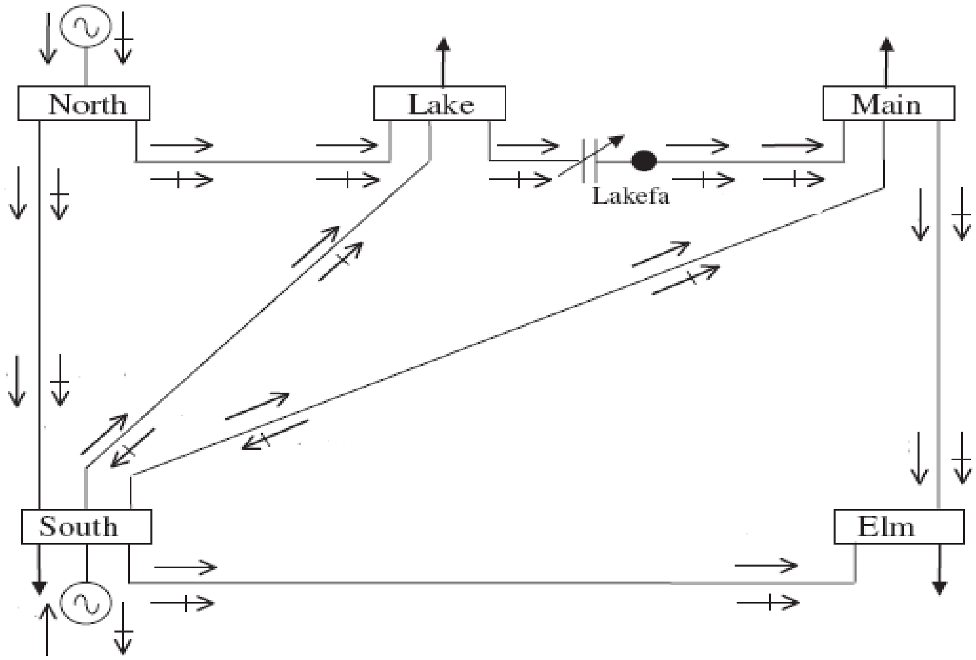


Fig 6.3: bus network problem statement with TCSC

- North – bus 1
- South – bus 2
- Lake – bus 3
- main – bus 4
- elm - bus 5

As can be seen lakefa region is newly created for tcsc.

Simulation using Haddi Saddat software:

```
basemva=100;accuracy=0.0001;maxiter=10;
         %  bus   bus   volt    angle ---load--- ---generator--- injected---
          %  no   code   mag   deg   mw      mvar   mw     mvar  Qmin Qmax mvar
busdata=  [1      1      1.06     0    0        0        0        0        0      0       0
             2      2     1.0       0    0        0       90.9     0        0     200     0
             3      0     1.0       0    45      14.89   0        0        0       0       0
             4      0     1.0       0    39.97  4.99     0        0        0       0       0
             5      0     1.0       0    67       9.95    10       0        0       0       0
             6      0     1.0       0    0         0        0        0        0       0       0];

   %line data
           % bus bus   R          X        0.5B      line code
            % nl  nr   pu         pu        pu       tap setting
linedata = [  1    2    0.020   0.060   0.030     1.0
                 1    3    0.080   0.240   0.025     1.0
                 2    3    0.060   0.180   0.020     1.0
                 2    4    0.060   0.180   0.020     1.0
                 2    5    0.040   0.120   0.015     1.0
                 3    6    0.005   0.015   0.005     1.0
                 6    4    0.005   0.015   0.005     1.0
                 4    5    0.080   0.240   0.025     1.0 ];

Lfybus      %form bus admittance matrix for power flow
Lfnewton    %power flow solution method for power flow
Busout      % prints power flow solution
%generator data
%        generator  Ra  Xd'   H
gendata=[ 1         0   0.20  20
             2         0   0.16  4  ];

Trstab      %performs the stability analysis
```

Solution:

Power Flow Solution by Newton-Raphson Method

Maximum Power Mismatch = 2.82685e-010

No. of Iterations = 10

Bus	Voltage	Angle	------Load------		---Generation---		Injected
No.	Mag.	Degree	MW	Mvar	MW	Mvar	Mvar
1	1.060	0.000	0.000	0.000	53.989	9.068	0.000
2	1.050	-0.684	0.000	0.000	90.900	-1.796	0.000
3	1.027	-3.383	45.000	14.890	0.000	0.000	0.000
4	1.026	-3.596	39.970	4.990	0.000	0.000	0.000
5	1.021	-4.012	67.000	9.950	10.000	0.000	0.000
6	1.027	-3.491	0.000	0.000	0.000	0.000	0.000
Total			151.970	29.830	154.889	7.271	0.000

Enter faulted bus No. -> 1

Enter the bus to bus Nos. of line to be removed -> [1,2]

Enter clearing time of fault in sec. tc = 0.4

Enter final simulation time in sec. tf = 10

Plot comparing stability curves with and without TCSC:

Fig 6.4: When fault at bus 1, line removed 12:

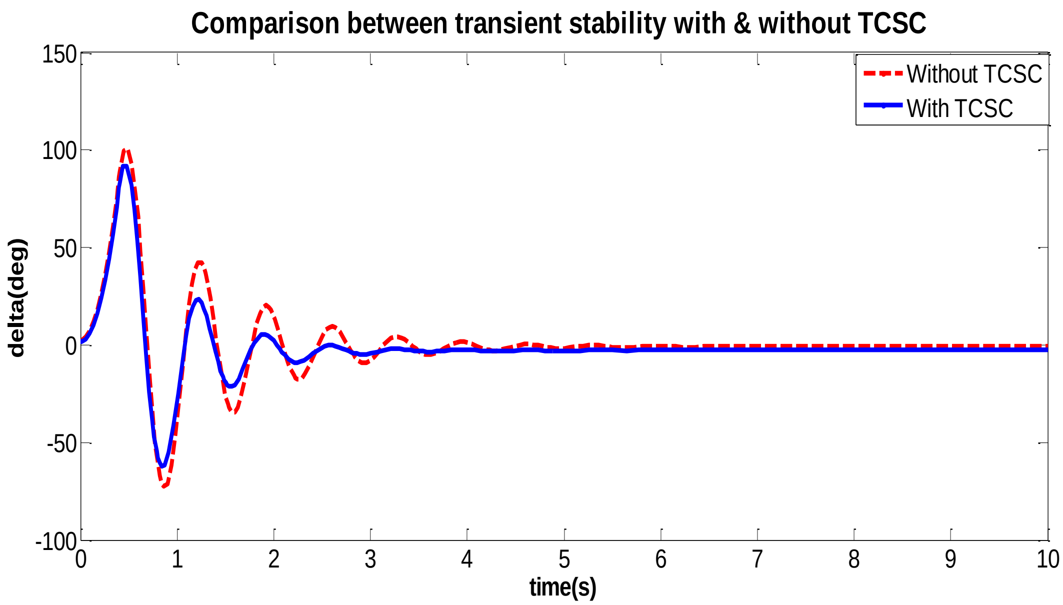


Fig 6.5 :When fault at bus 2 ,line removed 23:

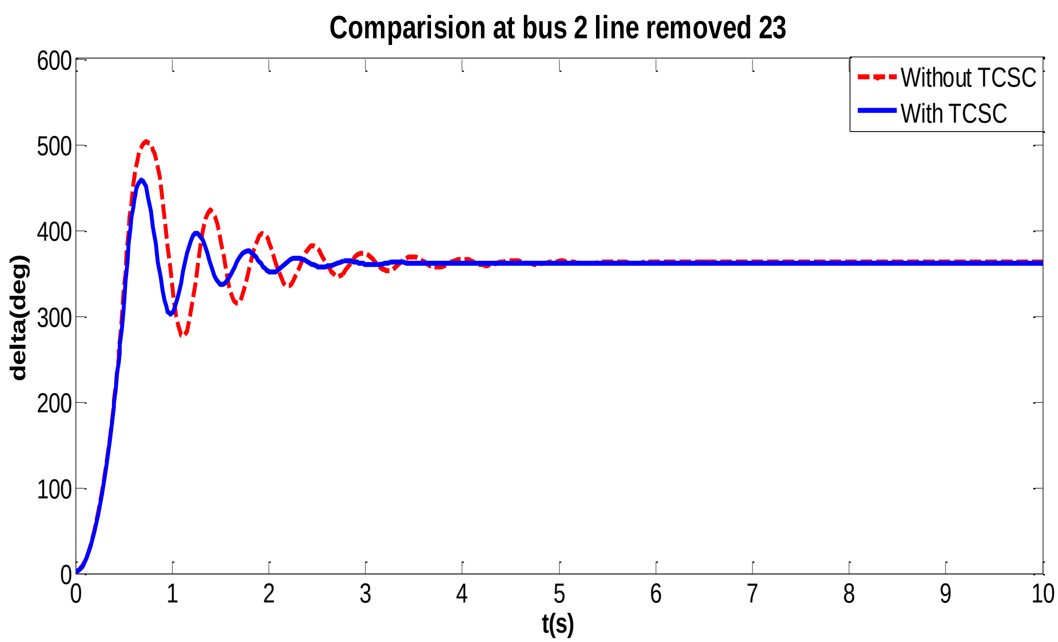


Fig 6.6:When fault at bus 2 ,line removed 25:

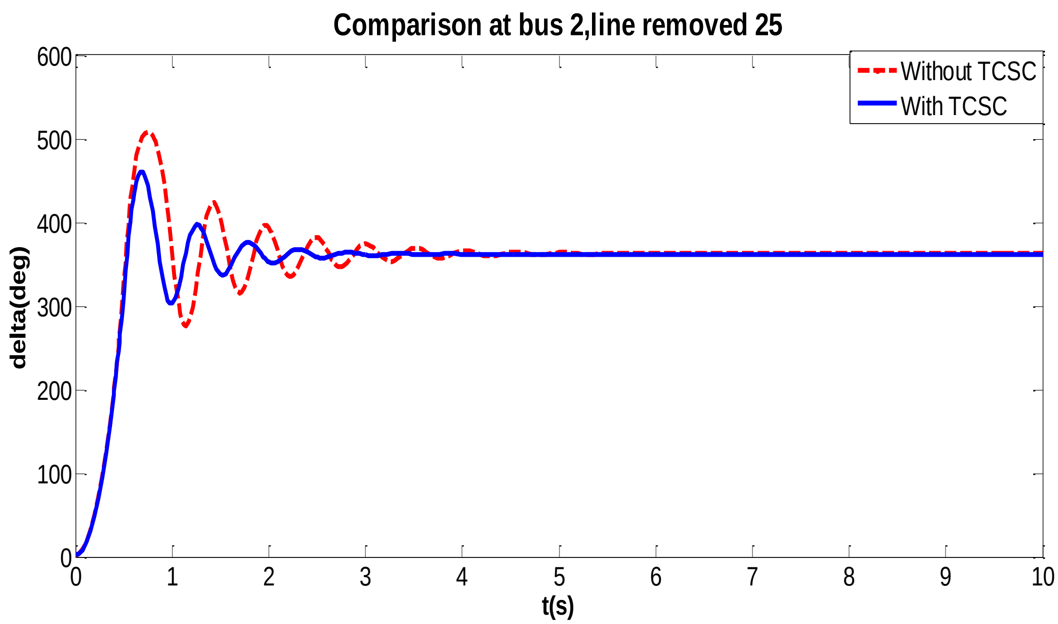


Fig 6.7:When fault at bus 3 ,line removed 13:

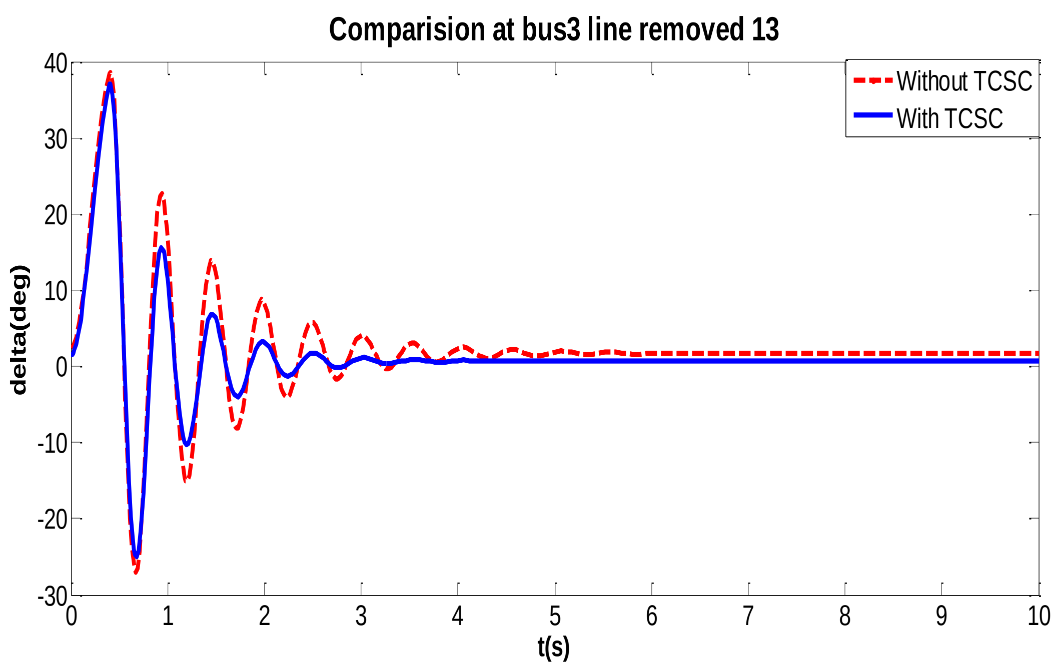


Fig 6.8:When fault at bus 3 line removed 34 (without tcsc)and 36 (with tcsc):

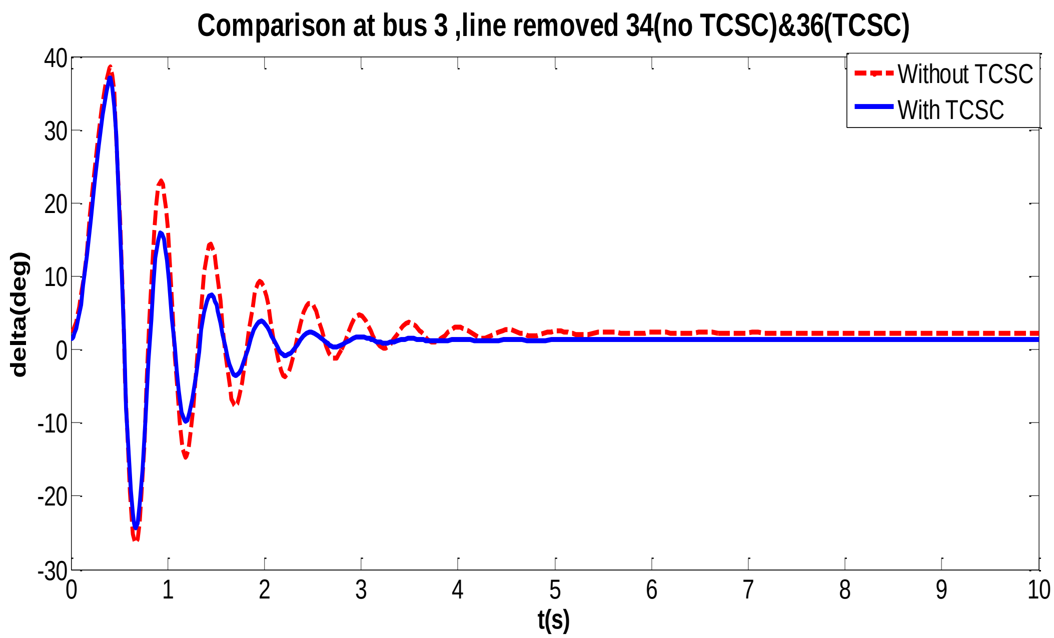


Fig 6.9 :When fault at bus 4,line removed 45:

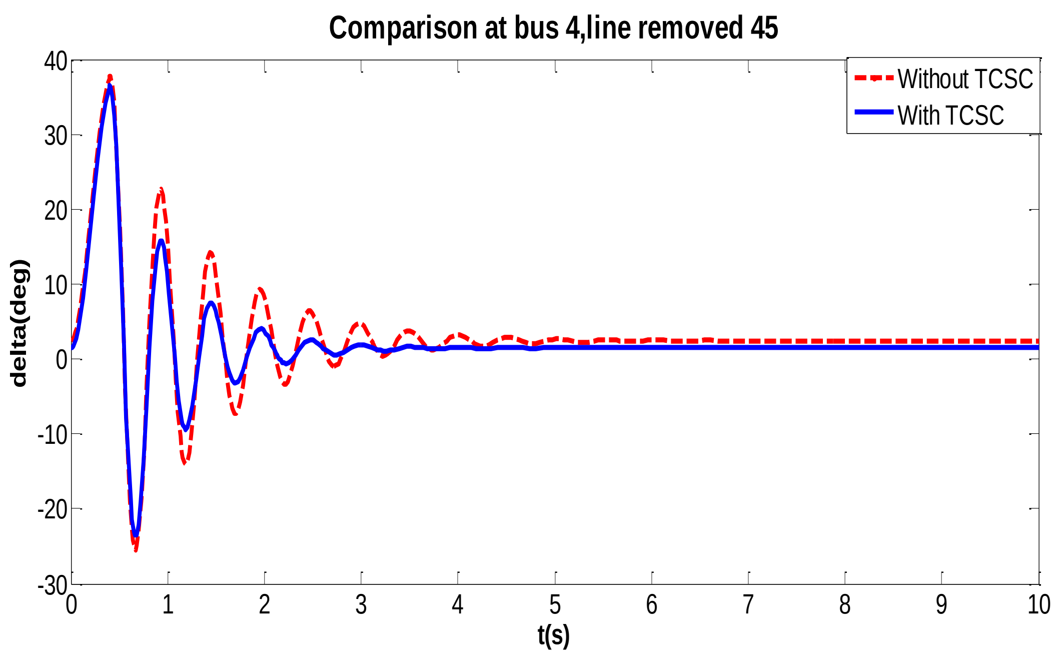


Fig 6.10:Fault at 4,line removed 24:

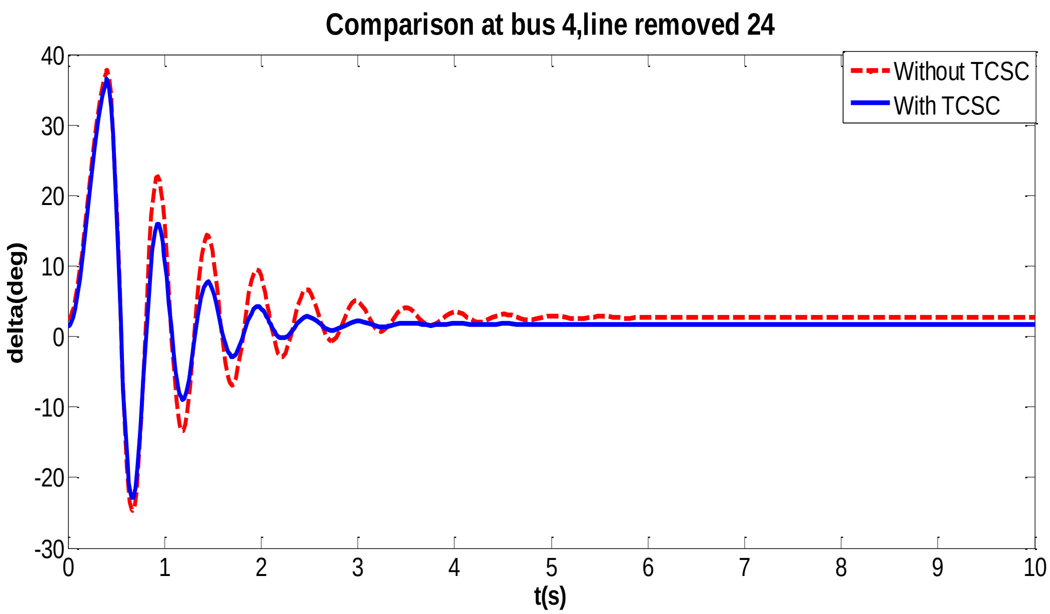
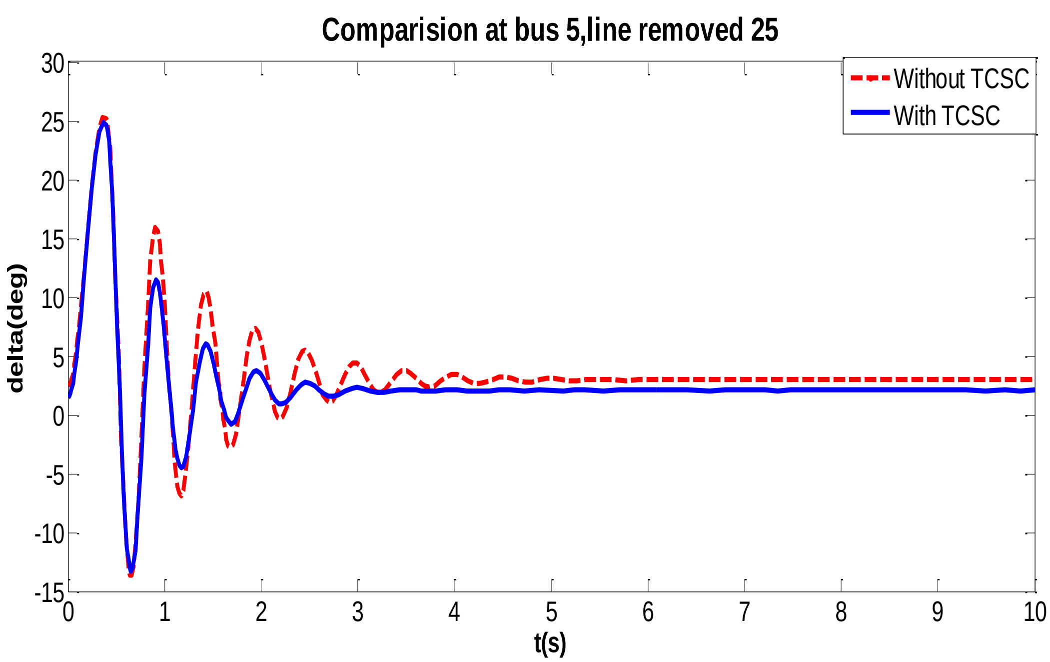


Fig 6.11: Fault at 5 line removed 25:



CONCLUSION

The comparision of simulations of both the both the networks shows the TCSC controller enhances stability of power system. From the transient analysis it is quiet clear that electromechanical damping increases on using these controllers. For large interconnected systems it is essential.

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